BULLET AND FRAGMENT
HAZARD TESTING

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BULLET AND FRAGMENT HAZARD TESTING

BACKGROUND

An August 1992 meeting involving US and UK representatives included a USN technical presentation on bullet and fragment hazard tests. Discussions arose concerning the cardinal purpose of and the complexity of issues surrounding the tests, and the recognition that it would be advantageous for the UK and the US to arrive at a bilateral agreement on the nature and use of those tests. This situation paper resulted from those discussions.

The Issues Involved. A general review of the rationales for conducting bullet and fragment tests reveals areas of differences and disagreement at least as related to the UK and US approaches to the conduct of their respective bullet and fragment impact tests. Aspects of the dialogue concerned

- the use of single vs multiple fragments;

- the shape, nature, weight and velocity of the projected objects (fragments vs bullets);

- the significance of accumulating data for historic, comparative, and predictive purposes as opposed to a focus on meeting a sanctioned passing criterion;

- the reproducibility of test results; and

- the utility and applicability of an international agreement on a multi-bullet impact test.

The need for subjecting a munition to any multiple projectile test and especially to both multiple fragment and multiple bullet tests is still frequently questioned even within single services. Cause for the questioning emanates from perceptions and observations that the requirements are often circumvented, results do not consider the effects of large fragments, projectile launch methods are site-specific, and multiple impacts damage the target more and increase the possibility of a detonation reaction.

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Knowledgeable representatives both in the US and UK readily acknowledge the difficulties both of attempting to identify a single generic projectile impact threat and of striving to offer one test for screening. (UK test establishments currently use a bullet impact test for screening and are considering a fragment attack test.) UK authorities dislike the multi-fragment test defined in the US MIL-STD-2105 because they perceive that the orientation of the cubes at impact is not controlled and that the multi-bullet procedure is not realistic. They suggest the use of a more controlled test in which, for example, single, flat-ended cylinders are projected at the target -- single projectiles to enhance repeatability and flat-ended cylinders to produce the most severe response.

Test Result Repeatability and Predictability. I and others generally believe that the experience and technology currently available are sufficient to define fragment hazard assessment tests that are both affordable and repeatable. Coupled with comprehensive threat analyses, a uniform test methodology would provide invaluable information necessary to support the development of reliable predictive technologies. The primary impediment to defining repeatable tests, however, seems to be the lack of agreement on the character of the fragment(s) to be used in the test(s). If we could surmount that hurdle, test establishments could more appropriately examine the efficacy of requiring multiple impacts and could attempt to confirm or refute the repeatability of test results among various organizations and nations. While an existing UN agreement on a multi-bullet impact test has been suggested as a possible starting point, an appropriate schedule for defining and reaching multi-national (or even US inter- and intra-service) agreement on tests m this area is unclear for the reasons discussed below.

Significance of the Threat. While a munition system can be exposed to many different threats during its life, its response to bullet or fragment impact and the significance of the consequences of any ensuing reaction will depend on the design of the munition, its configuration and its location when the reaction occurs. For example, a 200() pound sea mine detonating on board a navy destroyer would perhaps be fatal whereas the same weapon detonating on an aircraft carrier might not be fatal unless sympathetic detonation occurred. Similarly, one might ask if there is significant concern that a 40mm or 76mm or 5" bullet will detonate if it is hit by fragments from a threat weapon as long as that round does not sympathetically detonate. Consequently, diverse technical approaches have been discussed and investigated in attempts to improve platform and munition storage survivability when those munitions are exposed to combat-induced stimuli. The test regimes and protocols that have arisen from those investigations, however, have tended to focus on characterizing (and decreasing) the vulnerability of munitions to those combat-induced stimuli. Improved platform survivability has been realized not only from improved response of munitions to tests such as bullet and fragment attack tests, but also from employment of improved storage conditions that offer enhanced protection for the munitions. For example, while the US Navy traditionally uses the bullet impact test as a general purpose kinetic energy deposition test, US Army evaluators use the bullet impact test on ammunition stowed in tanks to assess the vulnerability of the tanks.

Diversity is also associated with opinions about the significance of and control of various factors that influence the outcome of bullet and fragment attack tests. Bullets and fragments may cleanly transit, tumble within, or lodge in target material, and, in so doing, may cause damaged target material to display different reactions. That variability raises many questions such as: Does a fragment test produce a stimulus that occurs in sympathetic detonation? To what degree, if any, should parameters such as case hardness, charge density, porosity, projectile size, velocity, trajectory, and initial incidence be considered in assessing the outcome of those tests?

DISCUSSION OF THE ISSUES

Bullet Attack. Single or multiple bullet attack and the caliber bullet to use have been the subject of many discussions in the United States for 15 years. Bullet impact testing has been conducted at various times and for various reasons with a variety of bullet sizes. Those have included, but were not limited to: 5.56mm, 7.62mm, 11.4mm (.45 caliber), 13.5mm (.50 caliber), 20mm AP (Armor Piercing), 20mm DU (Depleted Uranium), 23mm HEI (High Explosive Incendiary), and 40mm HEI. While much of the early testing was with single bullet attacks, concerns were being raised within the testing community as early as 1980 about the effects of multiple bullet attack. Information from Los Alamos Scientific Laboratory indicated that "...the first hit in an HE charge causes damage and reduces charge density, effectively increasing HE sensitivity. The second hit is then far more likely to cause detonation." The standardized use of 12.5mm (.50 caliber) bullets and a multiple bullet attack was first adopted as a hazard classification test for Insensitive High Explosives (IHE). This test protocol was carried over into the United Nations protocol for hazard division 1.6 articles and substances. In an effort to reduce the number of tests and test items required, the multiple bullet impact test was incorporated in MIL-STD-2105; it calls for a sequenced impact of three .50-caliber (12.5mm) bullets having a nominal weight of 710 grains (46g), a velocity of 2700 ft/sec and an impact energy of 15.5 kJ.

Fragment Attack. The purpose of fragment testing has been stated as the need to determine the reaction of munitions or components to an energy source that simulates the effect of nearby detonation of a threat weapon.

Although this purpose sounds simple, a 1992 NIMIC workshop identified at least four separate applications of fragment testing information:

(1) Hazard Classification Testing
(2) Historical comparison--The ordnance community responsible for acceptance of munitions into service needs evidence on which to base their safety and suitability assessments
(3) The research community needs the data to evaluate new energetic materials, new techniques for improving performance or safety, and to test new theories of munition-related phenomena
(4) Munition designers need data on which to base their designs in order to meet performance and safety requirements

MIL-STD-2105, with some amalgamation of those purposes m mind, included a multiple fragment test for US munitions that requires nearly simultaneous impact of the test item by two to five one-half inch mild steel cubes having a nominal weight of 250 grains (16.2g), a velocity of 8300 ft/sec and an impact energy of 51.8kJ. But even that test represents a composite of compromises. It is based on an estimate of the fragment mass and velocity from several potential threat weapons. The cubical shape was a compromise chosen to represent "chunky' type fragments usually produced by the detonation of bombs and projectiles. The ½-inch size was chosen to represent the approximate peak of the fragment mass distribution. The impact velocity was chosen to represent some of the higher velocity fragments which are found in those distributions. The fact that the cube would tumble was felt to approximate reality in that the fragment orientation at impact would not be known. An additional strong motivation was that there already existed a rather extensive data base of fragment impact testing which had been conducted using cubical fragments.

We all recognize that the fragment attack test using cubical fragments has problems: the orientation of the cube cannot be controlled; impact could occur on either a corner (point) or a side (flat); and depending on the orientation, the type of reaction induced in the target could be different. Thus, repeatability from test-to-test is difficult to achieve. And because MIL-STD-2105 gives a performance-type specification for the multiple fragment impact test, i.e., it specifies allowable impact velocity tolerances as well as the number of cubes that must impact the target, different groups and agencies have devised different methods of meeting this specification.

There are some interesting concepts that we might want to pursue, however. For example, evidence shows that the interval between impacts during any multiple impact test may not be critical even to the extent that materials damaged days earlier in testing still exhibited many of the properties of increased sensitivity. This feature might allow a compromise between the single versus multiple impact groups. A series of single impact tests spread over a reasonable time period on the same test item might achieve many of the desired results.

As another possibility, we might encourage investigations of the effects of substituting spherical fragments for the compromise cubically shaped representative of a "real world" fragment. Substituting various diameter spherical fragments might aid in providing consistency even through it or any chosen fragment shape would not represent the totally random sized and shaped fragments from a threat weapon.

One other point to be made about the multiple fragment test is that it should not be viewed as a substitute for a sympathetic detonation test. The results of a multiple fragment impact test may yield clues about sympathetic detonation behavior but it cannot predict it. Even though many fragments hit and penetrate the acceptor during sympathetic detonation testing, the acceptor is not an isolated unit in the open; it is surrounded by other units and structures that provide confinement. At the same time that it is being impacted, it is being exposed to the blast wave and possible thermal effects. Thus, the sympathetic detonation environment is, potentially, much more severe than that of the simple multiple fragment impact test.

THE WAY AHEAD

Over the years, various suggestions have been offered concerning the use of impact tests to determine the reaction of munitions or munition components. Many agree that multiple projectile tests preclude understanding the cause of any reaction that occurs because of the unknown condition of already damaged material. While this might be true, projectile impact into previously damaged material cannot be eliminated as a possible real world scenario.

I and others have suggested that we consider an approach analogous with the slow heating and fuel fire duet of tests; i.e., that we consider the use of "bracketing" tests in which two kinetic energy tests bracket high and low energy projectile impacts. For example, a single .50 caliber bullet at a given velocity could be used as the low energy projectile. The upper level energy projectile could be a single right circular cylindrical fragment travelling at the speed of an average fragment from a viable threat warhead as determined by a threat hazard analysis.

A different approach to understanding munition response to fragment impact is being developed by my UK colleagues at CINO. They have developed a Protocol for Fragment Impact Testing that consists of sequentially firing single fragments into a test round. They start just below the calculated shock threshold of the energetic material and proceed with further impacts depending on the response received in the preceding impact.

I conclude by saying that, while some organizations and nations have requirement and test definitions for a bullet attack test, and the US has requirements and definitions for multiple bullet and multiple fragment impact tests, there is still wide disparity in views about the need for these tests, the significance of their results, the detailed technical aspects of conducting the tests, and the utility and applicability of the results once we get them. To me, then, it is obvious that further work is needed before we can reach mutually agreeable requirements for and definitions of these multiple impact tests.

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VIEWGRAPH 1
BULLET AND FRAGMENT HAZARD TESTING
COVER SLIDE

BULLET AND FRAGMENT HAZARD TESTING

ISSUES

- **SINGLE VS MULTIPLE FRAGMENTS**
- **PHYSICAL CHARACTERISTICS OF PROJECTED OBJECTS**
- **DATA SIGNIFICANCE**
- **REPRODUCIBILITY OF TEST RESULTS**
- **UTILITY OF INTERNATIONAL AGREEMENT**

VIEWGRAPH 2
BULLET AND FRAGMENT HAZARD TESTING
ISSUES

BULLET AND FRAGMENT HAZARD TESTING

QUESTIONS

- IS A MULTIPLE PROJECTILE TEST NEEDED?
- NEED BOTH MULTIPLE FRAG AND MULTIPLE BULLET TESTS?
- OBSERVATIONS
  - REQUIREMENTS OFTEN CIRCUMVENTED
  - RESULTS DO NOT CONSIDER LARGE FRAGMENT EFFECTS
  - PROJECTILE LAUNCH METHODS ARE SITE-SPECIFIC
  - MULTIPLE IMPACTS MORE DAMAGING THAN SINGLE IMPACTS
  - MULTIPLE IMPACTS INCREASE POSSIBILITY OF DETONATION

VIEWGRAPH 3
BULLET AND FRAGMENT HAZARD TESTING
QUESTIONS

BULLET AND FRAGMENT HAZARD TESTING

PERCEPTIONS

- CUBE ORIENTATION AT IMPACT NOT CONTROLLED
- MULTI-BULLET PROCEDURE NOT REALISTIC
- NEED MORE CONTROLLED TEST
  - SINGLE PROJECTILES ENHANCE REPEATABILITY
  - FLAT-ENDED CYLINDERS PRODUCE MOST SEVERE RESPONSE

VIEWGRAPH 4
BULLET AND FRAGMENT HAZARD TESTING
PERCEPTIONS

BULLET AND FRAGMENT HAZARD TESTING

REPEATABILITY

- COUPLE THREAT ANALYSIS & TEST METHODOLOGY
- TEST FRAGMENT CHARACTERISTICS
- REPEATABLE TESTS WOULD PERMIT EXAMINATION OF MULTIPLE IMPACT EFFICACY
- POSSIBLE STARTING POINT IS UN AGREEMENT ON MULTI-BULLET IMPACT TEST

VIEWGRAPH 5
BULLET AND FRAGMENT HAZARD TESTING
REPEATABILITY

BULLET AND FRAGMENT HAZARD TESTING

SIGNIFICANCE OF CONSEQUENCES

- **RESPONSE DEPENDENT ON MUNITION DESIGN, CONFIGURATION AND LOCATION**

EX) 2000 POUND SEA MINE DETONATING ON DESTROYER MAY BE FATAL; DETONATING ON CARRIER MAY NOT BE FATAL.

EX) WHAT IS CONSEQUENCE OF FRAG IMPACT ON 40 OR 70mm BULLET?

VIEWGRAPH 6
BULLET AND FRAGMENT HAZARD TESTING
SIGNIFICANCE OF COSEQUENCES

BULLET AND FRAGMENT HAZARD TESTING

DIVERSITY OF TECHNICAL CONSIDERATIONS

- PLATFORM SURVIVABILITY INCREASED THROUGH IMPROVED RESPONSE OF MUNITIONS AND ENHANCED PROTECTION IN STORAGE

- INFLUENCING FACTORS
  - BULLETS AND FRAGMENTS MAY TRANSIT, TUMBLE WITHIN, OR LODGE IN TARGET MATERIAL CAUSING DIFFERENT REACTIONS IN DAMAGED TARGET MATERIAL
  - USN USES BI AS GENERAL PURPOSE KINETIC ENERGY DEPOSITION TEST; US ARMY USES BI ON AMMUNITION STOWED IN TANKS TO ASSESS TANK VULNERABILITY
  - FRAGMENTS MAY OR MAY NOT PRODUCE STIMULUS FOR SYMPATHETIC DETONATION

VIEWGRAPH 7
BULLET AND FRAGMENT HAZARD TESTING
DIVERSITY OF TECHNICAL CONSIDERATIONS

BULLET AND FRAGMENT HAZARD TESTING

US HISTORY

- EARLY TESTING - MOSTLY SINGLE BULLET ATTACKS
- 1980 - TESTING COMMUNITY CONCERNED WITH MULTIPLE BULLET ATTACK
- LOS ALAMOS SCIENTIFIC LABORATORY
  - FIRST HIT INCREASES CHARGE SENSITIVITY
  - SECOND HIT MORE LIKELY TO CAUSE DETONATION
- ADOPTED .50 CAL BULLETS AND MULTI-BULLET ATTACK TEST
  - AS HAZARD CLASSIFICATION TESTS FOR INSENSITIVE HE
  - AS UN PROTOCOL FOR HAZARD DIVISION 1.6
- 1991 - MULTIPLE BULLET IMPACT TEST ADDED TO MIL-STD-2105
  - SEQUENCED IMPACT OF THREE .50 CALIBER (12.5mm) BULLETS
  - BULLET WEIGHT - 710 GRAIN (46G)
  - IMPACT VELOCITY - 2700 FT/SEC
  - IMPACT ENERGY - 15.5kJ

VIEWGRAPH 8
BULLET AND FRAGMENT HAZARD TESTING
US HISTORY

BULLET AND FRAGMENT HAZARD TESTING

FRAGMENT TESTING

PURPOSE

- DETERMINE REACTION TO EFFECTS OF NEARBY DETONATION

APPLICATIONS (1992 NIMIC WORKSHOP)

- HAZARD CLASSIFICATION TESTING
- HISTORICAL COMPARISON
- PERFORMANCE AND SAFETY ASSESSMENTS
- DESIGN DATA FOR NEW MUNITIONS
- NEW ENERGETIC MATERIAL EVALUATION FOR IMPROVING PERFORMANCE OR SAFETY
- EVALUATION OF NEW TECHNIQUES

VIEWGRAPH 9
BULLET AND FRAGMENT HAZARD TESTING
FRAGMENT TESTING

BULLET AND FRAGMENT HAZARD TESTING

MULTIPLE FRAGMENT TEST

- MULTIPLE FRAGMENT TEST REQUIREMENTS
  - NEARLY SIMULTANEOUS IMPACT BY MILD STEEL CUBES
  - FRAGMENT WEIGHT - 250 GRAINS (16.2G)
  - IMPACT VELOCITY - 8300 FT/SEC
  - IMPACT ENERGY - 51.8 kJ

- REQUIREMENTS BASED ON COMPROMISES
  - MASS AND VELOCITY ESTIMATED FROM THREATS
  - CUBICAL SHAPE - "CHUNKY" FRAGMENTS IN DETONATION
  - ½" SIZE - APPROXIMATE PEAK OF THE FRAGMENT MASS DISTRIBUTION
  - IMPACT VELOCITY - HIGH END OF VELOCITY DISTRIBUTION
  - TUMBLING CUBE - REAL FRAGMENT ORIENTATION UNKNOWN
  - EXISTING DATA BASE ON CUBICAL FRAGMENTS

VIEWGRAPH 10
BULLET AND FRAGMENT HAZARD TESTING
MULTIPLE FRAGMENT TEST

BULLET AND FRAGMENT HAZARD TESTING

CRITICISMS OF MULTIPLE FRAGMENT TEST

- CUBE ORIENTATION NOT CONTROLLED
  - REACTION OF TARGET IS ORIENTATION DEPENDENT
  - TEST REPEATABILITY DIFFICULT TO ACHIEVE

- DIFFERENT GROUPS USE DIFFERENT METHODS

VIEWGRAPH 11
BULLET AND FRAGMENT HAZARD TESTING
CRITICISMS OF MULTIPLE FRAGMENT TEST

BULLET AND FRAGMENT HAZARD TESTING

INVESTIGATIONS TO CONSIDER

- INTERVAL BETWEEN IMPACTS DURING MULTIPLE IMPACT TEST MAY NOT BE CRITICAL
  - SERIES OF SINGLE IMPACT TESTS SPREAD OVER A REASONABLE TIME ON THE SAME TEST ITEM MIGHT ACHIEVE MANY OF THE DESIRED RESULTS

- SPHERICAL FRAGMENTS INSTEAD OF CUBICAL
  - SPHERICAL FRAGS MAY PROVIDE SOME CONSISTENCY
  - ANY SHAPE WOULD NOT REPRESENT TOTALLY RANDOM SIZED AND SHAPED FRAGMENTS FROM THREAT WEAPON

VIEWGRAPH 12
BULLET AND FRAGMENT HAZARD TESTING
INVESTIGATIONS TO CONSIDER

BULLET AND FRAGMENT HAZARD TESTING

RELATION TO SYMPATHETIC DETONATION TESTS

- MULTIPLE FRAGMENT TESTS DO NOT PREDICT SYMPATHETIC DETONATION
  - CAN YIELD CLUES ABOUT SYMPATHETIC BEHAVIOR

- SYMPATHETIC DETONATION TEST ENVIRONMENT MAY BE MORE SEVERE THAN MULTIPLE FRAGMENT IMPACT TEST ENVIRONMENT

VIEWGRAPH 13
BULLET AND FRAGMENT HAZARD TESTING
RELATION TO SYMPATHETIC DETONATION TESTS

BULLET AND FRAGMENT HAZARD TESTING

SUMMARY

- WIDE DISPARITY IN VIEWS ABOUT NEED FOR MULTIPLE BULLET & MULTIPLE FRAGMENT IMPACT TESTS
- CONSIDER CONCEPT OF TWO KINETIC ENERGY TESTS THAT "BRACKET" HIGH AND LOW ENERGY PROJECTILE INPUTS
- FURTHER WORK NEEDED

VIEWGRAPH 14
BULLET AND FRAGMENT HAZARD TESTING
SUMMARY